Fault scarp of the 1959 M7.6 Hebgen Lake, Montana, earthquake causing damage to barn (photo by I.J. Witkind).

Fault scarp of the 1983 M7.3 Borah Peak, Idaho, earthquake (photo by Gary E. Christenson).

Christenson, Batatian, Nelson

GUIDELINES FOR EVALUATING SURFACE-FAULT-RUPTURE HAZARDS IN UTAH

UGS MP 03-6

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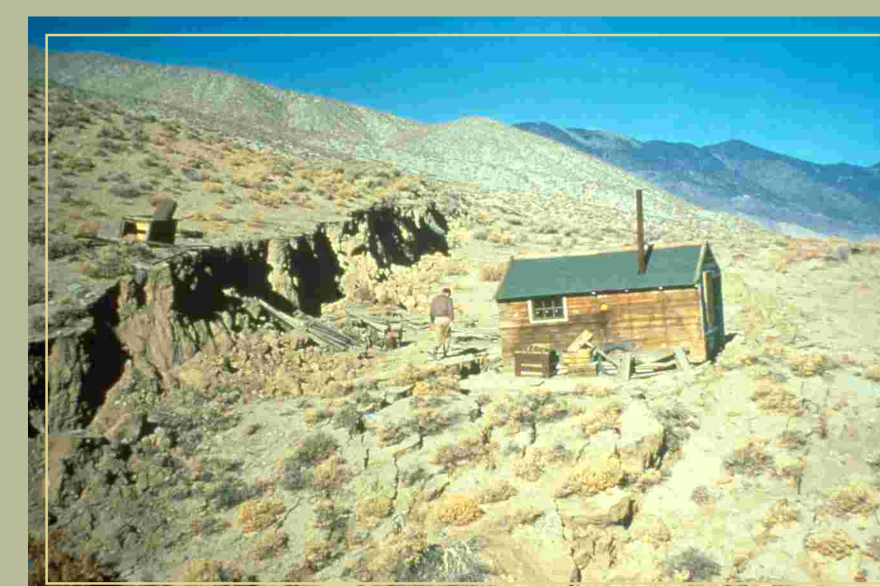
by

Gary E. Christenson, L. Darlene Batatian, and Craig V Nelson

Fault scarp of the 1934 M6.6 Hansel Valley, Utah, earthquake (photo by Frederick J. Pack, from the collection of R.B. Smith).



Fault scarp of the 1954 M6.8 Dixie Valley, Nevada, earthquake (photo by K.V. Steinbrugge).

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L. Darlene Batatian,
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UTAH GEOLOGICAL SURVEY

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UGS Editorial Staff

J. Stringfellow	Editor
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Gary E, Christenson,
Utah Geological Survey

L. Darlene Batatian,
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Western GeoLogic, LLC

ABSTRACT

The purpose of these guidelines is to outline appropriate surface-fault-rupture-hazard investigation techniques and report content to ensure adequate studies to protect the public, aid in land-use regulation, and facilitate risk reduction. Faults are grouped into Holocene (<10,000 years), Late Quaternary (<130,000 years), or Quaternary (<1.6 million years) activity classes to determine the need for site-specific study and setbacks. The Utah Geological Survey (UGS) recommends site-specific studies for all critical facilities and structures for human occupancy along Holocene faults, and for critical facilities along Late Quaternary faults. For non-critical facilities for human occupancy along Late Quaternary faults, and for all structures along Quaternary faults, studies are either recommended to assess the hazard and risk to aid in decision-making, or are considered optional. For well-defined faults, we recommend a special-study area 500 feet wide on the downthrown side and 250 feet wide on the upthrown side. For buried or approximately located faults, we recommend a special-study area 1000 feet on either side of the mapped fault where at least surficial geologic studies are conducted to identify possible faults for further study.

A site-specific surface-fault-rupture-hazard evaluation typically includes a literature review, aerial photograph analysis, and field investigation, usually including surficial geologic mapping and trenching to determine the age, displacement, and dip of faults. Setbacks are then determined based on these factors, footing depths, and the criticality of the facility. Risk-reduction measures in addition to setbacks include foundation reinforcement and disclosure. Surface-fault-rupture-hazard studies must be signed and stamped by the licensed Utah Professional Geologist performing the study.

INTRODUCTION

Purpose

The purpose of establishing guidelines for evaluating surface-fault-rupture hazards in Utah is to:

- protect the health, safety, welfare, and property of the public by minimizing the potentially adverse effects of surface fault rupture;
- assist local governments in regulating land use and provide standards for ordinances;
- assist property owners and developers in conducting reasonable and adequate studies;
- provide engineering geologists with a common basis for preparing proposals, conducting investigations, and recommending setbacks from faults; and
- provide an objective framework for preparation and review of reports.

Earthquakes produce a variety of hazards, including strong ground shaking, liquefaction, and landslides as well as surface fault rupture. These guidelines pertain only to surface fault rupture, which is displacement of the ground surface along a tectonic fault. These guidelines do not pertain to ground-surface displacements caused by non-tectonic faults as defined by Hanson and others (1999), including those resulting from liquefaction and landslides. In Utah, most known faults capable of causing large surface-faulting earthquakes are normal faults in which fault displacement at the surface is primarily vertical with one side dropping down relative to the other along a fault plane dipping beneath the downthrown side. Such surface faulting commonly recurs along existing fault traces. If a normal fault were to break the ground surface through the foundation of a building, significant structural damage or collapse could occur, causing injuries and perhaps loss of life. Engineering design to reduce damage from surface fault rupture to an acceptable level may be impractical; therefore, site-specific investigations are needed to accurately locate Quaternary faults, determine their level of activity and paleoseismic characteristics, and establish appropriate building setbacks and other risk-reduction measures prior to development. Maps designating special-study areas within which surface-fault-rupture-hazard studies are recommended have been prepared for Weber, Davis, Salt Lake, Utah, Cache, western Wasatch, and eastern Tooele Counties. The maps are available at each county planning department, and many local governments in these areas have adopted these maps in ordinances requiring special studies.

The purpose of surface-fault-rupture-hazard studies is to use the characteristics of past surface faulting at a site as a scientific basis for providing recommendations to reduce the potential for damage and injury from future, presumably similar, surface faulting. However, performance of these studies and adherence to their recommendations do not guarantee safety because significant uncertainty remains due to our limited understanding of surface-faulting processes, the possibility of future ruptures in previously unfaulted locations, and practical limitations common to investigations. Also, these guidelines address only hazards related to surface faulting. Other earthquake hazards and non-earthquake-related geologic hazards must also be addressed as part of a comprehensive geologic-hazards study.

A site-specific surface-fault-rupture-hazard evaluation typically includes a literature review, aerial photograph analysis, and field investigation, usually including surficial geologic mapping and subsurface investigations consisting of excavating and logging trenches. These guidelines outline appropriate study methods, report content (map and trench-log scales, setback recommendations), and expectations of the reviewer. The guidelines are based largely on minimum standards adopted by Salt Lake County (2002), which were developed from existing guidelines and standards in Utah and elsewhere in the western U.S., including: California Division of Mines and Geology (1986a, 1986b); Association of Engineering Geologists, Utah Section (1987); Robison (1993); Hart and Bryant (1997); and Nevada Earthquake Safety Council (1998).

These guidelines represent the recommended minimum acceptable level of effort in conducting surface-fault-rupture-hazard studies in Utah. Adherence to these guidelines will help ensure adequate, cost-effective studies and minimize review time. Considering the complexity of evaluating surface faulting, additional effort beyond the minimum outlined in these guidelines may be required at some sites to adequately address the hazard. These guidelines are mainly designed for siting new buildings for human occupancy. They are not designed for use in siting lifelines (highways, utilities, pipelines), which commonly must cross faults, or water impoundment and storage facilities (dams, water tanks, lagoons). Investigation methods are the same for these facilities, but setbacks and other hazard-reduction techniques may vary.

Background

Consideration of surface-faulting hazards in land-use planning in Utah was greatly strengthened in the early 1970s when Cluff and others (1970, 1973, 1975) completed their investigations and maps of faults along the Wasatch Front in northern Utah. These aerial-photograph-based maps presented the first comprehensive compilation of fault locations usable by local governments, and increased awareness of the hazard posed by the Wasatch, East Cache, and West Cache fault zones. Early paleoseismic trenching studies (Swan and others, 1980, 1981a, 1981b) further highlighted the hazard by documenting multiple Holocene ruptures on the Wasatch fault.

Recognizing the earthquake risk, local governments, particularly in northern Utah, began adopting ordinances requiring fault and other geologic-hazard investigations prior to development. Local government staff relied heavily on developers' consultants as professional experts responsible for evaluating surface-fault-rupture hazards and recommending adequate risk-reduction measures for proposed developments. Consultants' reports would sometimes be sent to the Utah Geological Survey (UGS) for review, but in general technical regulatory reviews were not systematically performed prior to 1985.

This informal review process lasted until June 1985 when the UGS initiated the Wasatch Front County Hazards Geologist Program, funded through the U.S. Geological Survey's National Earthquake Hazards Reduction Program (Christenson, 1993). County geologists hired in Weber, Davis, Salt Lake, Utah, and Juab Counties began preparing surface-fault-rupture and other hazard maps and assisting city and county planning departments in requiring and reviewing site-specific studies. Since then, various published guidelines for surface-fault-rupture-hazard studies have included those of the Association of Engineering Geologists, Utah Section (1987); Nelson and Christenson (1992); Robison (1993); Christenson and Bryant (1998); Batatian and Nelson (1999), and Salt Lake County (2002).

Many Wasatch Front cities and counties have enacted geologic-hazards ordinances that adopt surface-fault-rupture-hazard special-study-area maps that define areas where site-specific studies are required prior to approval of new development. The primary objective in these ordinances is to protect life safety and reduce economic loss in an earthquake causing surface faulting. An earthquake along one of the major known Quaternary faults in Utah can result in 6 feet (2 m) or more of displacement of the ground surface (Machette and others, 1992; Hecker, 1993; Black and others, 2003). To address surface-fault-rupture hazards, most local government ordinances prohibit construction of habitable structures and critical facilities across "active" faults. Ordinances typically define active faults by a simple age criterion: active faults have evidence for displacement during Holocene time (about 10,000 years ago to the present). Some ordinances expand the active-fault definition to include older Quaternary faults when siting critical facilities, and some exclude avoidance of faults with 4 inches (100 mm) or less of displacement.

Practical engineering measures are used to reduce risks for many geologic hazards such as landslides and liquefaction. However, designing a building to withstand significant fault displacement at the ground surface is usually not practical from an economic, engineering, and architectural standpoint. Avoiding construction on fault traces is generally the most practical risk-reduction measure. Fault locations therefore should be considered in early phases of site design when property is subdivided and buildings sited. The primary purpose of a surface-fault-rupture-hazard evaluation is to evaluate the presence or absence of Quaternary faults and determine their level of activity. If faults are found and are sufficiently active to pose a threat, zones of deformation and amounts and directions of displacement must be determined and appropriate avoidance strategies such as building setbacks recommended.

Fault Activity Classes

A critical step in evaluating surface-fault-rupture hazards is to determine the age of most recent surface rupture on the fault to indicate its level of activity (activity class) and resulting need for site-specific studies (see Study Requirements below). Fault activity classes in the Basin and Range Physiographic Province, which includes western Utah and the Wasatch Front, are defined by the Western States Seismic Policy Council (WSSPC) in WSSPC Policy Recommendation 97-1 (Lund, 1998) as:

- Holocene fault - a fault that has moved within the past 10,000 years.
- Late Quaternary fault - a fault that has moved in the past 130,000 years.
- Quaternary fault - a fault that has moved in the past 1,600,000 years.

The latter two classes are inclusive; that is, Holocene faults are included within the definition of Late Quaternary faults, and both Holocene and Late Quaternary faults are included in Quaternary faults. The activity class of a fault is the youngest class based on the age of most recent surface faulting.

The UGS recommends use of these fault activity classes statewide in Utah, and recommends investigators consider all Quaternary faults to be Holocene unless data are adequate to preclude Holocene displacement and assign a Late Quaternary or Quaternary activity class. Unfortunately, studies to determine fault activity classes have not been performed on many faults in Utah, particularly outside the Wasatch Front. A statewide compilation summarizing existing fault data and giving estimates of the timing of most recent surface rupture on known Quaternary faults in Utah is found in Black and others (2003; updated from Hecker, 1993). However, Black and others (2003) was not prepared for use in assigning activity classes for purposes of land-use regulation. The timing of the most recent event given in Black and others (2003) represents a best (non-conservative) age estimate based on data in existing studies. These estimates, particularly for many pre-Holocene (Late Quaternary and Quaternary) faults, are typically based on limited reconnaissance studies and thus are not adequate to determine the activity class to assess the need for site-specific studies.

Faults for which paleoseismic studies at various levels of detail have been performed are listed in table 1 of Black and others (2003). In many cases, these paleoseismic studies are sufficiently detailed to determine the activity class of a fault. For example, paleoseismic studies (and numerous surface-fault-rupture-hazard evaluations) on the central segments of the Wasatch fault and the West Valley fault zone have shown them to be Holocene faults. However, in some cases, existing paleoseismic studies may not be adequate to assign an activity class to the fault. Thus, faults for which paleoseismic studies are inadequate or have not been performed must either be studied in more detail to determine the age of most recent surface faulting, or must be considered to be Holocene until adequate studies demonstrate otherwise.

Paleoseismic techniques typically used in studies to determine the age of most recent surface faulting are outlined in McCalpin (1996). Such studies may involve at least a reconnaissance of the entire length of the fault or fault segment to find evidence of the most recent surface faulting because investigations at a single site may be inconclusive and insufficient to assign an activity class. Also, Black and others (1996, figure 7, p. 14) show that not all traces within a fault zone with multiple traces reactivate in every event, and no pattern is evident to suggest which traces may reactivate. Therefore, at a site with multiple traces, the fault activity class of all traces should be taken to be that of the youngest trace.

Study Requirements

Once the activity class of the fault is established, the UGS recommends special studies be performed for various facilities (defined below) as follows (table 1):

- Holocene faults - studies are recommended for all structures for human occupancy and all critical facilities.
- Late Quaternary faults - studies are recommended for all critical facilities. Studies for other structures for human occupancy remain prudent (dePolo and Slemmons, 1998) but local governments should base decisions on an assessment of whether risk-reduction measures are justified by weighing the probability of occurrence against the risk to lives and potential economic loss. Earthquake risk-assessment techniques are summarized in Reiter (1990) and Yeats and others (1997).
- Quaternary faults - studies are recommended for all critical facilities. Studies for other structures for human occupancy are optional and local governments need not require studies because of the low likelihood of surface rupture, although surface rupture is still possible.

Critical facilities are Category II and III structures as defined in the 2000 International Building Code (IBC, table 1604.5, p. 297; International Code Council, 2000) and Category III and IV structures in the 2003 IBC (table 1604.5, p. 272; International Code Council, 2003), and include schools, hospitals, fire stations, high-occupancy buildings, water-treatment plants, and facilities containing hazardous materials (IBC building occupancy classes E, H, and I structures; see table 1).

Surface-fault-rupture-hazard special-study areas have been defined for most Quaternary faults along the Wasatch

Table 1. Study and setback recommendations and criticality factors (U) for IBC building occupancy classes (International Code Council, 2000).

IBC building occupancy class	Study and setback recommendations[1] Fault activity class H	LQ	Q	Criticality[3]	U[3]	Minimum setback[4]
A. Assembly	R	P	O	2	2.5	25 feet
B. Business	R	P	O	3	2.0	20 feet
E. Educational	R	R	R[2]	1	3.0	50 feet
F. Factory/industrial	R	P	O	3	2.0	20 feet
H. High hazard	R	R	R[2]	1	3.0	50 feet
I. Institutional	R	R	R[2]	1	3.0	50 feet
M. Mercantile	R	P	O	3	2.0	20 feet
R. Residential (R-1, R-2, R-3 [>10 dwelling units], R-4)	R	P	O	3	2.0	20 feet
R-3. Residential (R-3 [<10 dwelling units])	R	P	O	4	1.5	15 feet
S. Storage	O	O	O	—	—	—
U. Utility and misc.	O	O	O	—	—	—

[1] Fault activity class (H - Holocene, LQ - Late Quaternary, Q - Quaternary). Study and setback or other risk-reduction measure: R – recommended; P – considered prudent but decision should be based on risk assessment; or O – optional but need not be required by local government based on the low likelihood of surface rupture. Appropriate disclosure is recommended in all cases.
[2] Study recommended; setback or other risk-reduction measure considered prudent but decision should be based on risk assessment; appropriate disclosure is recommended.
[3] Criticality is a factor based on relative importance and risk posed by a building; lower numbers indicate more critical facilities. Criticality is included in setback equations by the factor U. U is inversely proportional to criticality to increase setbacks for more critical facilities.
[4] Use the greater of this minimum or the calculated setback.

Front. Where special-study areas have not been defined, the UGS recommends that the width of special-study areas vary depending on whether the fault is well defined (Hart and Bryant, 1997), or buried or approximately located:

- Well-defined fault - fault trace is clearly detectable by a geologist qualified to conduct surface-fault-rupture investigations as a physical feature at or just below the ground surface (typically shown as a solid line on a geologic map). Recommended special-study areas extend horizontally 500 feet (153 m) on the downthrown and 250 feet (76 m) on the upthrown side of mapped fault traces or outermost faults in a fault zone. In areas of high scarps where 250 feet (76 m) on the upthrown side does not extend to the top of the scarp, the special-study area is increased to 500 feet (153 m) on the upthrown side (Robison, 1993).
- Buried (concealed) or approximately located fault - fault trace is not evident at or just below the ground surface for a significant distance (typically shown as a dotted line for buried faults and a dashed line for approximately located faults on a geologic map), usually between well-defined traces. Recommended special-study areas extend horizontally 1,000 feet (306 m) on either side of the fault.

Where local governments have not delineated surface-fault-rupture-hazard special-study areas, the first step in a site-specific fault evaluation is to determine if the site is near one of the mapped Quaternary faults shown on the existing small-scale (1:500,000) map by Black and others (2003). If so, existing larger scale maps (if available) should then be examined, and aerial photograph interpretation and field investigations should be performed and detailed maps prepared as outlined in the Surface Investigations section of these guidelines to determine whether the fault is within 500 feet (153 m) of the site if the fault is well defined, or 1,000 feet (306 m) if the fault is buried or approximately located. If faults are found or suspected within these distances, subsurface investigations should be conducted as outlined in the Subsurface Investigations section of these guidelines.

At a minimum, studies as outlined in the Surface Investigations section should be conducted for all critical facilities, whether near a mapped Quaternary fault (Black and others, 2003) or not, to ensure that previously unknown faults are not present. If evidence for a fault is found, subsurface investigations are recommended.

Risk-Reduction Measures

Faults of all activity classes (Holocene, Late Quaternary, and Quaternary) exhibit a wide range of recurrence intervals and slip rates in Utah. Ideally, decisions regarding the need for risk-reduction measures for surface faulting are based on a risk assessment considering the time of the most recent event and average recurrence between events to calculate the probability of rupture within a particular time frame. However, paleoseismic data in Utah are generally insufficient, particularly for Late Quaternary and Quaternary faults, to make such calculations. Also, large uncertainties in fault behavior exist because of documented irregular recurrence intervals, possible clustering and triggering (contagion), and poor constraints on timing of prehistoric events, even where isotopic or radiogenic dating methods are used.

For these reasons, the UGS has not attempted to establish a rigorous probability-based criterion and recommends a simple time-of-most-recent-rupture criterion to identify faults for risk-reduction measures. Other states that address surface-fault-rupture hazards such as California (Hart and Bryant, 1997) and Nevada (Nevada Earthquake Safety Council, 1998) have similarly adopted a time-of-most-recent-rupture criterion, recommending risk-reduction measures for all facilities for human occupancy along Holocene faults. Nevada also recommends that critical facilities not be built straddling Late Quaternary faults, in part because most historical surface-faulting events in the Basin and Range Physiographic Province have been on Late Quaternary rather than Holocene faults (dePolo and Slemmons, 1998).

The most common surface-fault-rupture risk-reduction measure is avoidance using setbacks. Consistent with neighboring western states, most local government ordinances in Utah prohibit placing buildings in positions that straddle Holocene faults (for example, the Salt Lake County Geologic Hazards Ordinance; Salt Lake County, 2002). The UGS concurs with this requirement, and recommends setbacks from Holocene faults for all structures for human occupancy (occupancy classes A, B, F, M, R) and critical facilities (occupancy classes E, H, I) as shown in table 1.

The UGS also recommends that critical facilities be set back from Late Quaternary faults, and that, for other buildings for human occupancy, setbacks are prudent but decisions regarding setting back should be based on a risk assessment. For Quaternary faults, the UGS recommends that studies for critical facilities provide information needed for prudent decisions that weigh the probability of occurrence and need for setbacks and other risk-reduction measures against the risk to lives and potential economic loss. For other structures for human occupancy, the UGS believes setbacks from Quaternary faults are optional and need not be required by local governments because of the low likelihood of surface rupture. The UGS recommends appropriate disclosure at all sites potentially subject to surface fault rupture near any Holocene, Late Quaternary, or Quaternary fault, including disclosure of the existence of reports of studies that assessed the surface-fault-rupture hazard.

Some local government ordinances exempt faults having less than 4 inches (100 mm) of displacement from setback requirements, based largely on Youd (1980) who concludes that up to 4 inches (100 mm) of displacement generally causes damage that is likely not a life-safety threat. Although we do not categorically exempt small-displacement faults from setback requirements, certain structural risk-reduction options such as foundation reinforcement may be acceptable for some small-displacement faults in place of setbacks. Fault studies must still identify faults and fault displacements (both net vertical displacements and horizontal extension across the fault or fault zone), and consider the possibility that future displacement amounts may exceed past amounts. If structural risk-reduction measures are proposed, a structural engineer must provide appropriate designs and the local government should review the designs.

HAZARD EVALUATIONS

Minimum Qualifications of the Preparer

Surface-fault-rupture-hazard evaluation is a specialized discipline within the practice of engineering geology, requiring technical expertise and knowledge of techniques not commonly used in other geologic or geotechnical investigations. Fault investigations must be performed by or under the direction of engineering geologists specifically trained and experienced in such investigations, and the final report should be signed and sealed by the licensed Utah Professional Geologist conducting or directing the study and include a statement of their qualifications outlining their education and experience conducting similar studies. Minimum qualifications of the engineering geologist who performs a fault study include all of the following:

- An undergraduate or graduate degree in geology, engineering geology, geological engineering, or a related field with a strong emphasis on geologic course work, from an accredited college or university.
- Three full years of experience in a responsible position in the field of engineering geology in Utah, or in a state having similar geologic hazards and regulatory environment. This experience must include the application of technical expertise, including familiarity with local Quaternary geology, and knowledge of appropriate techniques in performing surface-fault-rupture-hazard studies.
- A current license as a Utah Professional Geologist.

Geologists preparing surface-fault-rupture-hazard studies are ethically bound first and foremost to protect public safety and property, and as such must adhere to the highest ethical and professional standards in their investigations. The geologists' conclusions, drawn from information gained during the investigation, must be consistent, objective, and unbiased. Relevant information gained during an investigation may not be withheld. Differences in opinion regarding conclusions and recommendations and perceived levels of acceptable risk may arise between consulting geologists performing studies and agency-employed or retained geologists working as reviewers for a public agency. Adherence to these guidelines should reduce these differences of opinion and simplify the review process.

Investigation Methods

Inherent in fault study methods is the assumption that future faulting will recur along pre-existing faults (Bonilla, 1970, p. 68; McCalpin, 1987, 1996) and in a manner generally consistent with past displacements (Schwartz and Coppersmith, 1984; Crone and others, 1987). The focus of surface-fault-rupture-hazard investigations is therefore to: 1) determine whether Quaternary faults may exist at a site, 2) accurately identify and locate faults, 3) determine the age of most recent surface rupture and activity class of the faults, and 4) estimate amounts and directions of past displacements to provide a scientific basis for recommending fault setbacks.

Special care should be taken in investigations where faults cross landslides. Geomorphic and subsurface features in fault zones and landslides may be similar, and investigations may be inconclusive regarding the origin of such features. Therefore, report conclusions should address uncertainties in the investigation, and recommendations for risk reduction should consider both fault and landslide hazards.

Surface Investigations

The most direct surface method of locating faults and evaluating fault activity is to map fault scarps and surficial geology. Faults may be identified by examining geologic maps and aerial photographs, and by directly observing young, fault-related geomorphic features. Surface investigations include detailed mapping of fault scarps. Topographic profiling of fault scarps can aid in estimating age and amounts of displacement (Bucknam and Anderson, 1979; Andrews and Bucknam, 1987; Hanks and Andrews, 1989; Machette, 1989; McCalpin, 1996). Detailed surface investigations help to identify fault scarps and other possible fault-related features such as sag ponds, springs, aligned or disrupted drainages, faceted spurs, grabens, and displaced landforms (terraces, shorelines) or Quaternary geologic units. Site-specific surficial geologic mapping depicts relations between faults and geologic units to help determine the location and age of faults, and is necessary to identify potential trench sites.

Subsurface Investigations

Trenching is generally required for surface-fault-rupture-hazard studies to accurately locate faults, determine the fault activity class, document the nature and extent of fault-related deformation, and measure fault displacements and orientations. Trenches are usually excavated perpendicular to fault traces. Because fault displacements may vary along strike, the investigation should determine the maximum displacement along a fault trace at a site and at least one trench should be excavated into the highest part of a scarp.

Zones of deformation are common along major fault traces. Such deformation typically consists of multiple discrete displacements on secondary shears and is particularly common in graben floors. The trench investigation must define the zone of deformation, and for sites in a graben, trenches must be excavated perpendicular to the bounding faults across the entire part of the site within the graben. Additional subsurface methods such as drilling and geophysical surveys may be used and should be clearly described in the report. Geophysical methods may be used to help identify faults in the subsurface to target trench sites, but do not provide sufficient information to preclude trenching. Taylor and Cluff (1973); Sherard and others (1974); Slemmons (1977); Wallace (1977); Hatheway and Leighton (1979); Bonilla (1982); Association of Engineering Geologists, Utah Section (1987); McCalpin (1987, 1996); and Slemmons and dePolo (1992) summarize investigation methods.

Trench location: The purpose of a trenching study and objectives in locating trenches vary depending on the type of development and design phase during which studies are performed. When studies are performed prior to site design, such as for multi-unit subdivisions, trenches are used to locate faults and recommend setbacks so that buildings can be placed outside the setback zones. Multiple trenches may be necessary to accurately delineate faults as they cross the property (figure 1).

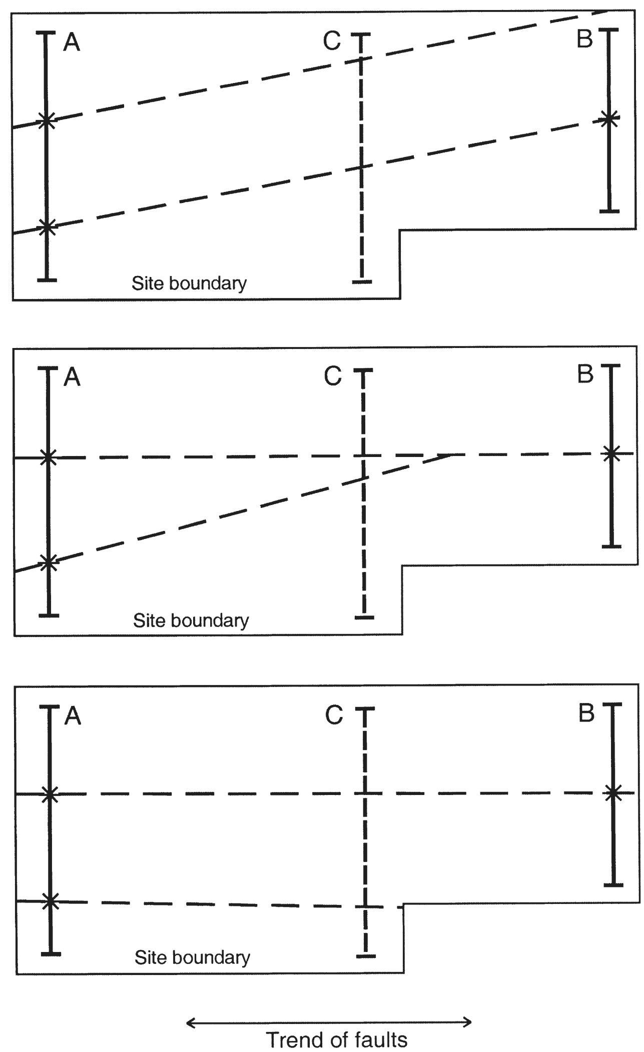

Figure 1. Three possible fault (dashed lines) configurations from fault exposures (X) in only two trenches (A, B) showing the need to measure fault orientations and excavate additional trenches (C), particularly when fault traces are not mappable at the surface.

When studies are performed after building locations have been laid out, trenches may be used to identify faults trending through the proposed building footprints (figure 2). The trenches must be oriented perpendicular to the trend of mapped fault traces at or near the site, and of adequate length to intercept faults projecting toward the proposed building footprint and any potential setback (figure 3). Trenches should therefore extend beyond the building footprint by at

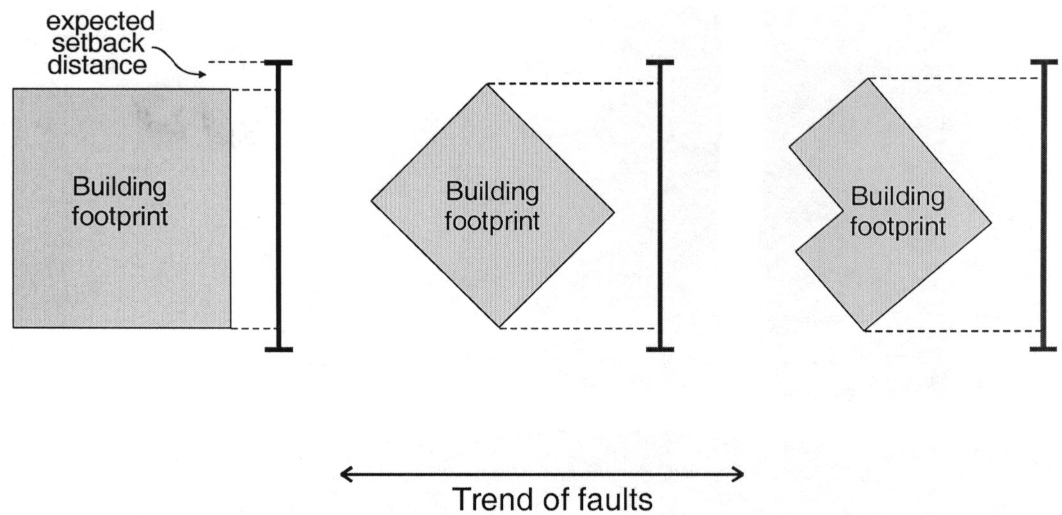

***Figure 2**. Fault trench length and orientation to investigate a building footprint. Trenches must extend beyond the footprint at least the expected setback distance for the IBC building occupancy class (table 1).*

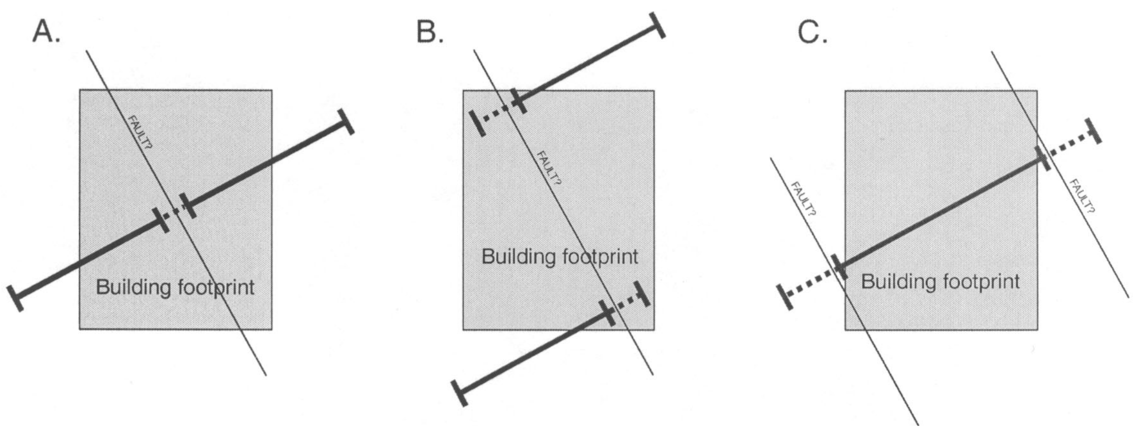

***Figure 3**. Potential problems caused by improper trench locations: A) gap between trenches, B) trenches without adequate overlap, and C) trench does not fully cover building footprint given fault trend (modified from Nelson and Christenson, 1992). Dashed lines indicate additional trench length needed.*

least the expected setback distance for the building type (table 1, figure 2) and to an adequate depth (see Depth of Excavation below).

More than one trench may be required to adequately investigate an entire site or building footprint, particularly if the proposed development is large, involves more than one building, or is characterized by complex faulting (figure 1). Trenches may be located outside proposed building footprints if compaction of trench backfill is not planned. When trenches need to be offset to accommodate site conditions, sufficient overlap should be allowed to avoid gaps in trench coverage perpendicular to the fault trend (figure 3).

Test pits are not an acceptable alternative to trenches. A series of aligned test pits perpendicular to the fault trend cannot adequately demonstrate the presence or absence of faulting because smaller displacement faults between test pits cannot be detected.

Trenches and faults must be accurately located on site plans and fault maps. Some local governments strongly recommend trench and fault locations be mapped by a registered professional land surveyor.

Depth of excavation: For suspected Holocene faults, trenches should extend through all unfaulted Holocene deposits and artificial fill to determine whether a fault has been active during Holocene time. However, an early Holocene fault may be concealed by unfaulted younger Holocene deposits and not be encountered within the practical depth limit of trenching, generally 15 to 20 feet (5-6 m) in most cases. For such trenches exposing unfaulted Holocene deposits where pre-Holocene deposits are below the practical depth of trenching, the practical limitations of the trenching should be acknowledged in the report and uncertainties should be reflected in the conclusions and recommendations. In cases where an otherwise well-defined Holocene fault is buried too deeply at a particular site to be exposed in trenches, the uncertainty in its location can be addressed by increasing setback distances along a projected trace. Borehole or geoprobe samples and cone penetrometer soundings with precise vertical control may help extend the depth of investigation. These same depth relationships apply to late Quaternary or Quaternary deposits when assessing suspected Late Quaternary or Quaternary faults at a site.

Trench investigations should be performed in compliance with current Occupational Safety and Health Administration (OSHA) excavation safety regulations (Occupational Safety and Health Administration, 1989; website: osha-slc.gov/SLTC/constructiontrenching/index.html).

Trench logging and interpretation: In preparation for logging, trench walls should be cleaned of backhoe soil smear to permit direct observation of the geology. Logging at a minimum scale of 1 inch equals 5 feet (1:60) is recommended, and accepted fault trench investigation practices (McCalpin, 1996) should be followed. Some form of vertical and horizontal logging control must be used and shown on the log. The log should document all pertinent information from the trench, including geologic-unit contacts and descriptions, faults and other deformation features, and sample locations.

The engineering geologist interprets the ages of sediments exposed in the trench and, when necessary, obtains samples for radiocarbon or other age determinations to constrain the age of most recent surface fault rupture. In the Lake Bonneville basin of northwestern Utah, the relation of deposits to latest Pleistocene Bonneville lake-cycle sediments is commonly used to infer ages of sediments, and thus estimate ages of surface-faulting events. Unfaulted Bonneville lake-cycle sediments in a trench therefore provide evidence that Holocene faulting has not occurred at that site.

Outside the Lake Bonneville basin and in the Lake Bonneville basin but above the highest shoreline, determining the age of surficial deposits is generally less straightforward and commonly requires advanced knowledge of local Quaternary stratigraphy and geomorphology, and familiarity with appropriate geochronologic techniques. At sites lacking deposits of known and sufficiently old ages, particularly to assess Holocene activity, radiocarbon or other age determinations of deposits that constrain the age of the most recent surface-faulting event may be required (McCalpin, 1996).

Field Review

Field reviews of trenches and trench logs by the Salt Lake County Geologist are required in Salt Lake County, as outlined in appendix A of the Salt Lake County Geologic Hazards Ordinance (Salt Lake County, 2002). Elsewhere in Utah, the UGS is commonly the reviewing agency and, although not required, the UGS appreciates being afforded the opportunity to perform field reviews of trenches. Because the UGS is interested in determining earthquake timing, activity classes, and recurrence intervals on all Quaternary faults in Utah, geologists performing surface-fault-rupture-hazard studies are requested to inform the UGS if trenches encounter stratigraphic relations and datable material that may be used to estimate the age of a paleoearthquake.

Fault Setbacks

The UGS recommends that Salt Lake County's fault setback calculation method for normal faults (Batatian and Nelson, 1999; Salt Lake County, 2002) as presented below be used throughout the state. The method should be used to establish the recommended fault setback for structures, depending on the fault activity class, as outlined in table 1. Variables used in the equations are shown in figure 4, and an example of a setback calculation is given in the appendix. This calculation method is for use with normal faults only. If reverse, thrust, or strike-slip faults are present, the geologist should provide the geologic justification in the report for the method used. Faults and fault setbacks should be clearly identified on the fault map (see Report Guidelines below).

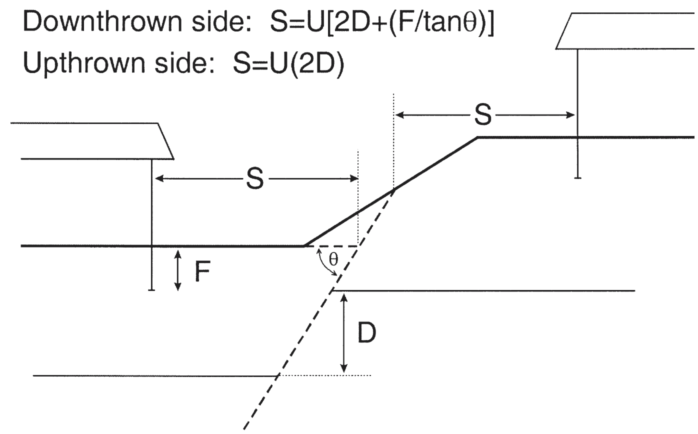

Figure 4. *Formulas and schematic diagram showing variables used to determine setbacks.*

Minimum setback recommendations are based on the proposed IBC building occupancy class (table 1). The calculated setback using the formulas presented below is compared to the minimum setback given in table 1, and the greater of the two is used. Minimum setbacks given in table 1 apply to both the downthrown and upthrown blocks. These setbacks apply only to surface faulting; greater setbacks may be necessary for slope, property boundary, or other considerations.

Downthrown Block

The fault setback for the downthrown block should be calculated using the following formula:

$$S = U\,[2D + (F/\tan\theta)]$$

where:

S = Setback within which buildings are not permitted.

U = Criticality factor, based on the IBC building occupancy class (table 1).

D = Expected fault displacement per event (use the maximum vertical displacement measured for past events or, if not measurable, estimated based on paleoseismic data). Along main traces where displacement is not measurable, a maximum estimated single-event displacement should be used.

F = Maximum depth of footing or subgrade portion of the building.

θ = Dip of the fault (degrees).

Setback distances on the downthrown block are measured from where the fault intersects the final grade level for the building (figure 4). For dipping faults, if the fault trace daylights in the face of a scarp above final building(s) grade, the setback is taken from where the fault would intersect the final grade level for the building(s) rather than where it daylights in the scarp.

Upthrown Block

Because the setback is measured from the portion of the building closest to the fault, whether subgrade or at grade, the dip of the fault and depth of the subgrade portion of the structure are irrelevant in calculating the setback on the upthrown block. The setback for the upthrown side of the fault should be calculated as:

$$S= U\ (2D)$$

Setback distances on the upthrown block are measured from where the trace daylights at the surface, commonly in a scarp. Minimum setbacks apply as discussed above.

Report Review and Applicability

The UGS recommends review of all reports by a licensed Utah Professional Geologist qualified in surface-fault-rupture-hazard studies and acting on behalf of local governments to protect public safety and reduce risks to future property owners and taxpayers. The reviewer should evaluate the adequacy of the investigation, report, and setbacks, and provide recommendations to the local government regarding the need for additional work, if warranted.

Review requirements are outlined in local government ordinances. Surface-fault-rupture-hazard studies for sites in Salt Lake County that are reviewed by the Salt Lake County Geologist must satisfy minimum standards in the Salt Lake County Geologic Hazards Ordinance (Chapter 19.75, appendix A). Other local government ordinance requirements for studies are generally non-specific, and the UGS recommends the guidelines given herein be applied elsewhere throughout the state. If study or setback requirements in a local government ordinance exceed recommendations given herein, ordinance requirements must be met. Other state or federal regulations may supercede these guidelines.

REPORT GUIDELINES

Surface-fault-rupture-hazard reports in Utah are expected, at a minimum, to address the topics below. Site conditions may require that additional items be included.

A. Purpose and scope of investigation. Describe location and size of site and proposed type and number of buildings (if known).

B. Geologic and tectonic setting. Reference published and unpublished geologic literature with emphasis on current sources, and discuss Quaternary faults in the area, historical seismicity (particularly earthquakes attributed to area faults), and geodetic measurements where pertinent.

C. Site description and conditions. Include pertinent information on geologic units, geomorphic features, graded and filled areas, vegetation, existing structures, and other factors that may affect the fault study, site development plan, and choice of investigative methods.

D. Methods of investigation.

1. Review of published and unpublished maps, literature, and records concerning geologic units, faults, surface and ground water, and other relevant factors, with emphasis on current sources.

2. Stereoscopic interpretation of aerial photographs to detect fault-related topography, vegetation or soil contrasts, and all lineaments of possible fault origin. List source, date, flight-line numbers, and scale of aerial photos used (preferably 1:24,000 scale or larger).

3. Field observations of pertinent surface features, both onsite and offsite, including mapping of geologic units; geomorphic features such as scarps, springs and seeps (aligned or not), faceted spurs, and disrupted drainages; and geologic structures as needed, depending on site complexity. Other possible earthquake-induced features such as sand blows, lateral spreads, and other evidence of liquefaction and ground settlement should be mapped, described, and assigned ages. Profiling of fault scarps may provide a basis for estimating the age and amount of vertical displacement. Landslides, although they may not be conclusively tied to earthquake causes, should also be mapped and described.

4. Subsurface investigations including trenching for direct observation of continuous exposures of geologic units, soils, and geologic structures. Trenches must be of adequate length and depth as discussed above (see Investigation Methods section), and be carefully logged. The strike, dip, and vertical displacement (or minimum displacement if total displacement cannot be determined) of faults should be noted. The report should describe the criteria used to determine the age and geologic origin of the deposits encountered in the trenches, and clearly evaluate the presence or absence of Holocene, Late Quaternary, or Quaternary faults.

5. Other methods may be required to supplement trench data when special conditions or requirements for critical facilities demand a more intensive investigation. These may include the following methods:
   a. Test pits, boreholes, geoprobe holes, or cone-penetrometer tests. These may provide data on geologic units and ground water at specific locations. The number and spacing of data points must be sufficient to permit valid correlations and interpretations.
   b. Geophysical investigations. These are indirect methods (Chase and Chapman, 1976; Sharma, 1998) that require knowledge of the geology for reliable interpretation. Geophysical methods alone cannot prove the presence or absence of a fault or determine the age of faulting. Techniques may in-

clude seismic reflection, seismic refraction, ground-penetrating radar, or other methods such as magnetic intensity, electrical resistivity, or gravity.

c. Age determination. Techniques may include isotopic (radiocarbon, cosmogenic nuclide) and radiogenic (thermoluminescence, optically stimulated luminescence) analysis, soil-profile development, stratigraphic correlation (fossils, lithologic provenance), and other methods to date faulted and unfaulted units or surfaces (Forman, 1989; Noller and others, 2000).

E. Conclusions.

1. Summary of evidence establishing the presence or absence of faulting, and fault activity class, including ages and geologic origin of faulted and unfaulted stratigraphic units and surfaces.

2. Location of faults, including orientation and geometry of faults, maximum amounts of vertical displacement on faults, anticipated future offsets, calculation of setbacks, and delineation of setback (non-buildable) areas.

3. Degree of confidence in and limitations of data and conclusions.

F. Recommendations. Recommendations must be supported with geologic evidence and appropriate reasoning.

1. Recommended setbacks. These should be shown on the fault map.

2. Other recommended building restrictions, use limitations, or risk-reduction measures such as placement of detached garages, swimming pools, or other non-habitable structures in fault zones, or use of reinforced foundations for small-displacement faults.

3. Recommended inspection of building foundation excavations during construction to confirm surface and subsurface investigations.

G. References. Complete citations of literature and records used in the study, including personal communications.

H. Illustrations.

1. Location Map. The site location, topographic and geographic features, and other pertinent data should be identified, generally on a 1:24,000-scale USGS topographic base map.

2. Geologic Map(s). A regional-scale (1:24,000 to 1:50,000) map should show the geologic setting, including geologic units, faults, and general geologic structures in the area. Depending on site complexity, a site-scale geologic map may also be necessary to show geologic units, faults, seeps or springs, slope failures, lineaments investigated for evidence of faulting, and other geologic features existing on and near the project site. Scale of site geologic maps will vary depending on the size of the site and area of study; recommended scale is 1 inch = 100 feet (1:1,200) or larger. Site geologic cross sections may be included as needed to illustrate three-dimensional relationships.

3. Site Plan. The site boundaries, topographic contours, proposed building footprints (if known), existing structures, streets, slopes, drainages, trenches, boreholes/geoprobe holes/cone-penetrometer soundings, test pits, and geophysical traverses should be shown on this map. The map scale may vary depending on the size of the site and area covered by the study; the recommended scale is 1 inch = 100 feet (1:1,200) or larger. The site plan may be combined with the fault map (item 4 below).

4. Fault Map. The map should show the location of faults, including the locations of trenches or other subsurface investigations used to locate faults, location(s) of faults encountered in subsurface investigations, inferred location of the faults between trenches, recommended fault setback distances on each side of the faults defining non-buildable areas, topographic contours, and proposed building footprints (if known). Scale may vary depending on the size of the site and area covered by the study; recommended scale is 1 inch = 100 feet (1:1,200) or larger.

5. Trench and Test Pit Log(s). Logs are required for each trench and test pit excavated as part of the study whether faults are encountered or not. Logs are hand- or computer-generated maps of excavation walls that show details of geologic units and structures. Logs should be to scale and not generalized or diagrammatic, and may be on a rectified photomosaic base. The minimum scale (horizontal and vertical) should be 1 inch = 5 feet (1:60) with no vertical exaggeration. Logs should accurately reflect the features observed in the excavation, as noted below. Photographs do not substitute for trench logs.

   Logs should include: trench and test-pit orientation and indication of which wall was logged; horizontal and vertical control; top and bottom; stratigraphic contacts; stratigraphic unit descriptions including detailed lithology, soil classification, and contact descriptions; pedogenic soil horizons; marker beds; and faults and fissures. Other features of tectonic significance such as in-filled soil cracks, colluvial wedges, drag folds, rotated clasts, lineations, and liquefaction features including sand dikes and blows should also be shown. Interpretations of the age and origin of the deposits and any faulting or deformation should be included, based on depositional sequence. Fault orientation and geometry (strike and dip), and amount of displacement should be measured and noted.

Provide evidence for the age determination of geologic units. For suspected Holocene faults where unfaulted Holocene deposits are deeper than practical excavation depths, clearly state the study limitations.

6. Borehole Logs. Because boreholes are typically multipurpose, borehole logs should contain standard geotechnical and geologic data such as lithology descriptions, soil class, sampled intervals and sample recovery, blow-count results, static ground-water depths and dates measured, total depth of boreholes, drilling and sampling methods, and identity of the person logging the borehole. In addition, borehole, geoprobe hole, and cone-penetrometer logs for fault studies should include the geologic interpretation of deposit genesis for all layers.

7. Geophysical Data and Geologic Interpretations.

8. Photographs. Photos of scarps, walls of excavations, or other features may enhance understanding of site conditions and report conclusions.

I. Authentication. Include the signature and seal of the investigating licensed Utah Professional Geologist(s); qualifications giving education and experience in engineering geology and fault studies can be presented in resume format in an appendix (see J. Appendices below).

J. Appendices. Include supporting data relevant to the investigation not given in the text such as cross sections, conceptual models, fence diagrams, survey data, water-well data, and qualifications statements.

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APPENDIX

EXAMPLE SETBACK CALCULATION

Trenching along the Wasatch fault in southern Salt Lake County identified the main trace of the fault and a minor antithetic fault crossing a property. Displacement on the main fault could not be determined, except that it exceeded the 18-foot depth of the trench and the fault accommodated the entire down-to-the-west component of displacement (that is, no other parallel down-to-the-west traces exist in the zone). The main fault dips 70 degrees to the west. Total displacement on the antithetic fault was 2 feet, dipping 50 degrees to the east. Single-family dwellings with basements requiring 8-foot foundation depths are planned.

Main fault setback. Because the total displacement could not be measured, an average single-event displacement for the main trace of the Salt Lake City segment of the Wasatch fault of 8.5 feet is estimated based on data in Black and others (1996) and McCalpin (2002)*. Using D = 8.5 feet in the calculation:

Downthrown (western) block = $U[2D+(F/\tan\theta)]$
= $1.5[(2)(8.5)+8/\tan 70)]$
= $1.5(17+3)$
= 30 feet

Upthrown (eastern) block = $U(2D)$
= $1.5(2)(8.5)$
= 26 feet

Antithetic fault setback. Because we do not know whether the 2-foot displacement on the antithetic fault is an incremental or single-event displacement, we must assume it occurred in a single event.

Downthrown (eastern) block = $U[2D+(F/\tan\theta)]$
= $1.5[(2)(2)+8/\tan 50]$
= $1.5(4+7)$
= 17 feet

Upthrown (western) block = $U(2D)$
= $1.5(2)(2)$ = 6 feet
Because 6 feet is less than the 15-foot minimum
Setback = 15 feet

*Total single-event displacement data for the Salt Lake City segment are poor because in research trenches the total displacement has been spread over several traces. Black and others (1996, p. 15) determined that the combined single-event down-to-the-west displacement along all traces at the South Fork Dry Creek site ranged from 4.9-8.2 feet (1.5-2.5 m)/event, depending on the number of events assumed to displace the late Holocene debris flow at the site. McCalpin (2002, p. 23) estimated the total throw across the two major traces at the Little Cottonwood megatrench site and calculated about 8.5 feet (2.6 m)/event, near the upper end of the Black and others (1996) range. For purposes of setback calculations, a conservative estimate of 8.5 feet (2.6 m) is prudent.